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13. ABSTRACT (Maximum 200 words)

The long-term aim of this project is a better understanding of auditory processes which use across-frequency or across-ear temporal envelope difference cues to aid performance. Specific areas of investigation include comodulation masking release (CMR), the masking-level difference (MLD), temporal resolution, and the processing of amplitude and frequency modulation. The goal of the first proposed experiment is to examine the possible relation between CMR and auditory phenemona related to auditory scene analysis; the gola of the second experiment is to examine the possible relation between CMR and the MLD for narrowband noise maskers; the goal of the third experiment is to determine the extent to which across-frequency correlation of temporal envelope may influence gap detection for wideband stimuli; the goal of the fourth experiment is to determine whether masking release can be derived from cues based upon across-frequency coherence of frequency modulation; the goal of the fifth experiment is to examine a modulation masking phenomenon related to frequency modulation. The tasks will be signal detection in masking noise, temporal gap detection, and the detection of frequency modulation. Testing will be performed in a sound-treated room, using a 3AFC adaptive procedure.

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PROGRESS REPORT : "Auditory spectro-temporal pattern analysis," (AFOSR 90-0108)

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AIMS

The long-term aim of this project is a better understanding of auditory processes which use across-frequency or across-ear temporal envelope and modulation difference cues to aid performance. Areas of investigation include comodulation masking release (CMR), the masking-level difference (MLD), temporal resolution, and the processing of amplitude and frequency modulation. The goals of the five proposed experiments are to 1) examine the possible relation between CMR and auditory phenomena related to auditory grouping, or auditory scene analysis; 2) examine how CMR and MLD effects combine, and to examine the possible relation between CMR and the MLD for narrowband noise maskers; 3) to determine the extent to which across-frequency correlation of temporal envelope may influence gap detection for wideband stimuli; 4) determine whether masking release can be derived from cues based upon across-frequency coherence of frequency modulation; 5) examine a modulation masking phenomenon related to frequency modulation. The tasks involve signal detection in masking noise, temporal gap detection, and the detection of frequency modulation.

PROGRESS

Our research progress over the second year of this project is summarized as follows:

1. Projects completed during second year

a. The effect of modulation coherence on signal threshold in frequency-modulated noise bands : Project complete.

A series of four experiments was undertaken to ascertain whether signal threshold in frequency-modulated noise bands is dependent upon the coherence of modulation. The specific goal was to determine whether a masking release could be obtained with frequency modulation (FM), analogous to the comodulation masking release (CMR) phenomenon observed with amplitude modulation (AM). It was hypothesized that an across-frequency grouping process might give rise to such an effect. In experiments 1 - 3, maskers were composed of three noise bands centered on 1600, 2000,

and 2400 Hz; these were either comodulated or noncomodulated with respect to both FM and AM. In experiment 1, the modulation was sinusoidal and the signal was a 2000-Hz pure tone; in experiment 2, the modulation was random and the signal was an FM noise band centered on 2000 Hz. The results obtained showed that, given sufficient width of modulation, thresholds were lower in a coherent FM masker than in an incoherent FM masker, regardless of the pattern of AM or signal type. However, thresholds in multi-band maskers were usually elevated relative to that in a single-band masker centered on the signal. Experiment 3 demonstrated that coherent FM could be discriminated from incoherent FM. Experiment 4 gave similar patterns of results to the respective conditions of experiments 2 and 3 but for an inharmonic masker with bands centered on 1580, 2000, and 2532 Hz. While within-channel processes could not be entirely excluded from contributing to the present results, the experimental conditions were designed to be minimally conducive to such processes.

b. Relative contributions of envelope maxima and minima to comodulation masking release : Project complete

Comodulation masking release (CMR) is a phenomenon which demonstrates the sensitivity of the auditory system to aeross-frequency differences in the temporal modulation pattern of a complex waveform. In this paper, we review briefly some of the data on the physical parameters that affect CMR, and describe models that have been proposed to account for CMR: namely, models based upon envelope equalization/cancellation, across-frequency envelope correlation, and "dip listening." The literature previous to this study was ambiguous with regard to the relative importance of energy in the peak and dip regions of the waveform envelope. We therefore performed a series of experiments to investigate this issue. In the first experiment, we examined CMR for signals which resulted in either a uniform increment or uniform decrement in the masking noise centered on the signal frequency. This was accomplished by using a 20-Hz-wide noise band centered on 700 Hz as both the masker and as the signal, adjusting the phase angle between the signal and masker to either 0° (increment) or 180° (decrement). Conditions were examined where either zero, one, two, four, or six comodulated flanking bands were present. Results indicated positive CMRs for all conditions in which a comodulated flanking band was present. CMR increased as the number of flanking bands increased for intensity increments, but not for intensity decrements. The remaining experiments examined conditions where signals were present only in masker peaks, or only in masker dips. The results of these experiments indicated relatively large CMRs when the signal occurred in dip regions, but no CMR when the signal occurred in peak regions. Whereas the results of the above experiments were not compatible with the dip listening hypothesis of CMR, they did indicate that the stimulus cues which give rise to CMR appear to be derived primarily from the dip regions of the masking noise.

c. Consequences of temporal asynchrony for modulation detection interference: Project complete

The ability to detect the existence of amplitude modulation at a target frequency is reduced when amplitude modulation exists at a flanking frequency. This effect has been termed modulation detection interference (MDI) (Yost and Sheft, 1989). One explanation for MDI holds that the masking and target frequencies are grouped together by the auditory system such that it is difficult to analyze the modulation at each frequency separately. The present study investigated conditions where the asynchrony of temporal gating of the target and flanking frequencies was manipulated in order to make the frequencies more or less likely to be grouped together by the auditory system and perceived as originating from a single putative source. A second experimental manipulation attempted to perceptually segregate the masking and target frequencies on the basis of harmonicity. The results of the experiments indicated that manipulations that were intended to enhance the segregation of the masking and target frequencies reduced the magnitude of MDI effects. This generally supported an interpretation that MDI is related in some way to auditory grouping. A final experiment was done in which the subject had to detect the presence of amplitude modulation, but also had to identify which of two frequency components carried the modulation. The results showed that subjects were often poor in discriminating which of two frequencies was amplitude modulated, even when the modulation itself was clearly audible. It was concluded that part of the MDI effect might be due to the poor ability of the auditory system to associate modulation with the carrier of the modulation. The results of the present study did not specifically support the idea that MDI is related to auditory grouping by common modulation.

d. Masker envelope fluctuations and binaural masking release: Project complete

Several studies have indicated that the MLD can be reduced by the presence of energy that is relatively remote from the signal frequency. One interpretation of this result has been that the frequency selectivity for binaural hearing is relatively poor. The present experiments were designed to examine this issue further. In baseline conditions, a 500-Hz So or Sπ pure-tone was masked by a 40-Hz wide No narrowband noise centered on 500 Hz. In the experimental conditions, three 40-Hz-wide No flanking bands were also present, centered at 250, 750 and 1000 Hz. The flanking bands were either comodulated with the band centered on 500 Hz, or they were comodulated between themselves but independently from the 500-Hz band, or each of the flanking bands had an independent envelope. The results can be summarized as follows:

1) For uncorrelated envelopes, the NoSo threshold with flanking bands present was not significantly different from that of the baseline condition. This result is consistent with an interpretation that the flanking bands were so far removed from the signal frequency that they caused a negligible increase in the energy at the output of the auditory filter centered on 500 Hz.

2) For correlated envelopes, the NoSo threshold with flanking bands present was substantially better than that for the baseline condition. This result can be regarded as a CMR (across-frequency analysis of waveform envelope).

3) For uncorrelated envelopes, the NoSπ threshold with flanking bands present was *worse* than that for the baseline condition. This agrees with the classical finding that NoSπ detection is affected deleteriously by masking energy relatively remote from the signal frequency.

4) For the case of correlated envelopes, the NoSπ threshold with flanking bands present was again better than that of the baseline condition.

5) When the flanking bands were replaced by equal-energy pure tones, the NoSπ thresholds did not differ much from the baseline threshold. This shows that when the remote energy has a flat amplitude envelope, the NoSπ detection is affected neither negatively (as for uncorrelated envelopes) nor positively (as for correlated envelopes). This result suggests further that the effect of remote energy on the MLD is related strongly to the relation between the amplitude envelope at the signal frequency and the amplitude envelope at the remote frequencies.

6) When the flanking bands were comodulated among themselves, but independently from the 500-Hz band, the deleterious effects of the independent flanking bands on NoSπ detection was reduced. The interpretation was that the coherently modulating flanking bands could be perceptually segregated from the independently-modulating 500-Hz band, thus reducing their disruptive effects.

In summary, these results are consistent with an interpretation that across-frequency comparison processes similar to those contributing to monaural CMR may also contribute to NoSπ detection.

e. Gap detection in multiple narrow bands of noise as a function of spectral configuration: Project complete

This study sought to differentiate between the effect of stimulus bandwidth and the effect of number of activated auditory channels on gap detection in narrow bands of noise. The aim was to clarify the role of across-frequency analysis in temporal processing. Experiment 1 established that when total noise bandwidth is held constant at 100 Hz, gap detection improves as stimulus energy is distributed to both lower and higher frequencies. Experiment 2a showed that the effect was smaller, or was absent, when the cumulative stimulus bandwidth was increased from 100 Hz to 200 Hz. Experiment 2b confirmed that the benefit of spectral dispersion for the narrower cumulative bandwidth also held for a higher frequency region. The results suggested that in conditions where the cumulative stimulus bandwidth is relatively narrow and, concomitantly, gap detection is relatively poor, there is an advantage in dispersing the stimulus across a number of auditory channels. The advantage for the

distribution of energy across a range of auditory channels may be offset when the spectral spacing of bands exceeds a critical value.

2. Experiments Presently In Progress

a. Gap detection and modulation masking (Grose and Hall). CMR suggests that the auditory system is sensitive to across-frequency differences in modulation pattern. This raises the question of whether it is as sensitive to modulation differences due to the absence of activity (a silent interval) as it is to the presence of additional of activity (a signal). If so, gap detection in a narrow-band noise would be expected to be better in the presence of a comodulated flanking band than in the presence of a noncomodulated flanking band. In contrast, an auditory grouping hypothesis would predict that the presence of a comodulated flanking band would result in a fused auditory image of the two bands, rendering a momentary silent interval in one of the bands less noticeable. The present study was designed to test between these divergent hypotheses. Gap detection was measured in a 25-Hz-wide narrow-band noise centered at either 0.5, 1.0 or 1.5 kHz. A second 25-Hz band of noise, centered between 0.5 and 1.5 kHz, was then added which was either comodulated or noncomodulated with the target band. The most striking result was that gap detection deteriorated markedly with the addition of a second noise band, irrespective of its modulation pattern. Further testing suggested that this deterioration was due to a process of modulation masking. The variable data prevented a firm conclusion being drawn regarding the relative effect of a comodulated versus a noncomodulated flanking band. A manuscript on this project is in preparation.

b. CMR for comodulated signals (Hall). The issue of CMR for comodulated signals has been a question of interest for several years. However, the question has awaited the development of a definitive paradigm to address the issue. In our own previous paradigms, the signals were either comodulated narrow bands of noise (NBNs), or NBNs having no envelope correlation. The masker was a broadband unmodulated noise. The baseline condition for this experiment was detection for a single 50-Hz-wide NBN centered at 1000 Hz. In the experimental conditions, either two, three, five or 10 50-Hz-wide NBNs comprised the signals. The bands were spaced 100 or 200 Hz apart. Detection in the comodulated conditions was contrasted with detection in conditions in which the signals were noncomodulated, to assess the effect of comodulation. Masking release effects for comodulated signals in this paradigm appeared to be absent or small. Wright's (1990) work in this area has been more promising, but still was somewhat ambiguous about a possible facilitative effect of signal comodulation. We mention these experiments here because we are now looking at new conditions that are more likely to uncover a positive contribution of comodulation among signal components. The current work is examining the effect of signal comodulation in masker backgrounds that are highly uncertain.

c. Gap detection for multiple narrowband noise stimuli (Hall and Grose). One explanation of temporal resolution for wideband stimuli entails the registration of across-frequency correlation of temporal envelope. Even though such a hypothesis is consistent with previous data (Richards, 1987), it could be criticized as being less parsimonious than a hypothesis simply involving statistical summation of gap information across CBs. Further evidence is required to evaluate between the hypotheses. In the baseline condition of the present experiment, a 100-Hz-wide narrowband noise centered on 1000 Hz is presented *continuously* at a level of approximately 20 dB SL. In one of the three intervals (3AFC), a gap occurs in the stimulus, and the gap is adjusted adaptively (3-down, 1-up). In the experimental condition, the 100-Hz-wide noise band at 1000 Hz is again presented and adjusted in terms of detectable gap, but a second, continuous, comodulated 100-Hz wide is also presented at 700 Hz. (Bands are presented continuously because we have found that this makes results less subject to modulation masking than is the case for pulsed stimuli). However, the band at 700 Hz does not contain a gap. Thus the two bands are always comodulated, except when the gap is present. By an across-CB difference interpretation, better gap detection performance is expected in the experimental condition (where the gap is associated with an across-CB difference) than in the baseline condition. In our previous experiment showing advantage for multiple noise bands in gap detection (Grose and Hall, 1988), the noise bands were noncomodulated, except when the gap was present; in the proposed experiment, the bands will be comodulated, except when the gap is present (almost the converse of the previous experiment). The key strength of the present design is that an across-CB difference hypothesis predicts better performance in the experimental condition, but a "multiple looks" explanation does not (the gap occurs in only one of the bands). The data collected so far favor an across-CB difference hypothesis and suggest the interpretation that across-frequency differences in temporal envelope may provide one cue for gap detection of wideband stimuli.

Publications resulting from project to date.

Comodulation masking release and auditory grouping : Hall, J.W. and Grose, J.H. (**1990**). "Comodulation masking release and auditory grouping," Journal of the Acoustical Society of America **88**, 119-125.

Detection of Frequency Modulation (FM) in the presence of a second FM tone: Wilson, A.S., Hall, J.W. and Grose, J.H. (**1990**). "Detection of frequency modulation (FM) in the presence of a second FM tone," Journal of the Acoustical Society of America 88, 1333-1338.

Accounting for the variability in CMR : Moore, B.C.J., Hall, J.W., Grose, J.H. and Schooneveldt, G.P. (**1990**). "Some factors affecting the magnitude of comodulation masking release," Journal of the Acoustical Society of America 88, 1694-1702.

The effect of modulation coherence on signal threshold in frequency-modulated noise bands : Grose, J.H. and Hall, J.W. (**1990**). "The effect of coherence of modulation on signal detection in frequency modulated noise bands," Journal of the Acoustical Society of America **88**, 703-710.

Relative contributions of envelope maxima and minima to comodulation masking release : Hall, J.W. and Grose, J.H. (**1991**). "Relative contributions of envelope maxima and

minima to comodulation masking release," Quarterly Journal of Experimental Psychology, **43A**, 349-372.

Consequences of temporal asynchrony for modulation detection interference: Hall, J. W. and Grose, J. H. (**1991**). "Some effects of auditory grouping factors on modulation detection interference (MDI)," Journal of the Acoustical Society of America **90**, 3028-3035.

Masker envelope fluctuations and binaural masking release:
Hall, J.W. and Grose, J.H. (**1992**). "Masker envelope fluctuations and binaural masking release," in Auditory Physiology and Perception (Y. Cazals, L. Demany, and K. Horner, eds) (in press).

Gap detection in multiple narrow bands of noise as a function of spectral configuration: Grose, J.H. (**1991**). "Gap detection in multiple narrow bands of noise as a function of spectral configuration," Journal of the Acoustical Society of America **90**, 3061-3068.